Chapter 9.—Using Remote Sensing to Assess Anthropogenic Influences on Stream Temperature

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Abstract

In-stream water temperatures are regulated by a variety of intrinsic and extrinsic environmental variables dictated by the natural and anthropogenic state of a fluvial stream system. To evaluate how landscape scale processes relate to in-stream conditions, this study applies an integrated remote sensing and GIS-based approach to compare *in situ* measured stream-water temperatures with remotely derived proxies for land cover and land use in the John Day basin of east-central Oregon. Preliminary findings suggest that stream temperatures correlate more strongly with landscape variables assessed at the watershed level than at the reach scale, suggesting that instream conditions may be regulated by watershed characteristics present well beyond the traditional riparian corridor. This research lends insight to fish habitat modeling strategies by testing the utility and application of remotely derived landscape variables as proxies for stream habitat function, fish performance, and restoration potential.

Introduction

Rivers and streams flow through landscapes in constant contact with surrounding habitat. The ever changing landscape through which the stream flows is shaped by a plethora of natural and anthropogenic processes. Whether a stream flows in a straight channel through miles of continuous grassland, or it sweeps in a meandering path through intermingled patches of wetlands, urban areas and industrial parks, the relationship between the structure of the stream and the complexity of the landscape through which it flows are linked to the streams potential for rearing and maintaining healthy fish populations. In this conceptual model, the stream integrates landscape information, communicating the complexity of the watershed to fluvial system (see fig. 1). Evaluating the relationships between the landscape and the stream habitat is often confounded by this landscape complexity and the means by which it is traditionally represented in models designed to predict habitat suitability. Critical for relating landscape scale variables to in stream ecological indicators is an understanding of how the landscape communicates with the stream across varying spatial scales.

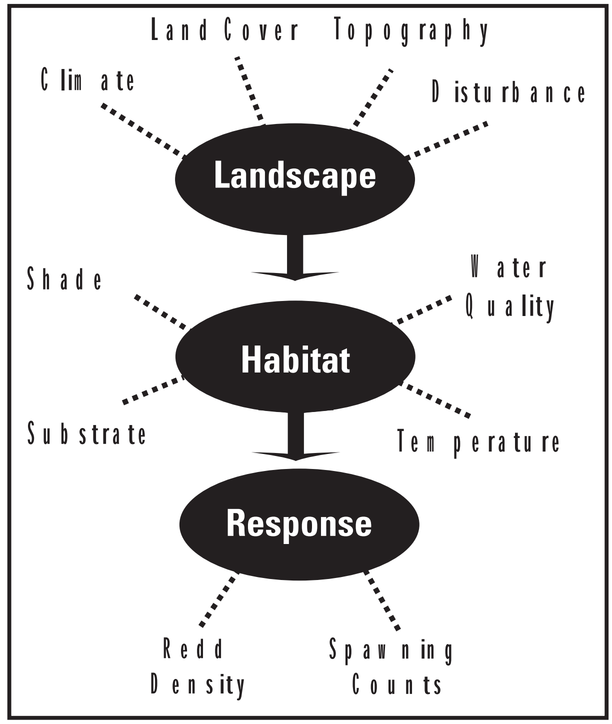

Figure 1. Conceptual model illustrating the connectivity between between parameters used to evaluate landscape, riparian habitat and the suitability (response) of that habitat for fish productivity.

Water temperature has direct and indirect effects on nearly all aspects of stream ecology and function. Changes in riparian vegetation, irrigation water-management practices and channel engineering are all potential human influences on water temperature. Understanding how stream water diversions (e.g., through culverts and irrigation canals), removal of stream buffers (e.g., through riparian clear cut harvests), and decoupling of the stream channel from the floodplain (e.g., through channelization and bank-hardening) relate to measured in-stream water temperatures is important for modeling fish habitat, for developing habitat restoration strategies, and for understanding overall human impacts on stream condition. Most management actions do not adequately consider the myriad environmental processes that drive stream temperature regimes nor do they acknowledge the wide variety of pathways by which human activities may affect stream temperature (Poole and Berman, 2001).

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We use satellite image-derived measures of vegetation that define the spatial and temporal variability in riparian buffer extent and floodplain wetness in concert with GIS hydrography layers that characterize and define the spatial extent of channel alterations and engineering to apply GIS-based spatial analysis tools to compare in situ measured stream-water temperatures with remotely derived proxies for water withdrawals from irrigation, loss of riparian vegetation from grazing and land use, and alterations to channel complexity. With an integrated remote sensing and GIS-based approach, we evaluate how remotely sensed landscape variables, namely Normalized Difference Vegetation Index and related metrics, correlate with measured in-stream water temperatures in the Middle Fork of the John Day River in east central Oregon (see fig. 2).

Figure 2. Map of the John Day subbasin in east-central Oregon, showing the trace of the John Day River and the study region along the Middle Fork (highlighted). Upper right corner schematic shows the basin's geographic location relative to the State border between Washington and Oregon.

This study explores the overall utility of satellite data for deriving landscape variables that can be used to evaluate the impacts of irrigation, clear cutting, wildlife grazing and channel alterations on habitat suitability and restoration efforts. The findings will lend insight to how remote sensing can improve the predictive capabilities of habitat models with regards to stream function, fish performance and restoration potential.

Study Region

This research focuses on the Middle Fork John Day (MFJD) of the John Day River in Grant County of east-central Oregon. Covering more than 500,000 acres, this watershed primarily is publicly owned forest (60%) with the remainder held privately as range and pastureland. Through the mid-1800s, the landscape of the MFJD was a largely untouched wilderness until the 1862 Canyon Creek gold strike brought thousands of placer miners and homesteaders to the region. The basin subsequently underwent various alterations as stream bottoms were cleared and planted to hay or grain, and stream courses were channelized and diverted for irrigation (Oliver, 1962). In the early mid-1900s, the drainage had been further developed for agriculture and more large-scale gold dredging that overturned spawning beds, altered stream configuration, and nearly decimated riparian vegetation. These and other historical and current land-management practices including placer mining, livestock overgrazing, irrigation withdrawals, land clearing, road building, logging and stream canalization have all changed the dynamics of the present day MFJD watershed (Stuart and Williams, 1988). Many of these changes are still evident in the modern landscape, rendering riparian habitat degradation the most serious anadromous fish habitat problem in the John Day River basin with approximately 660 degraded stream miles (Columbia River Inter-Tribal Fish Commission, 1995). Specifically, high seasonal water temperatures are commonly considered to be one of the major anadromous limiting factors in the John Day Subbasin (Columbia-Blue Mountain Resource Conservation and Development Area, 2005).

This specific region was chosen for study due to its land-use history, the relatively low impact of urbanization, the availability of remote sensing thermal data, (i.e., thermal infrared), and its potential for salmonid habitat modeling and restoration.

Data

The datasets used in this analysis include remotely sensed spectral satellite data (Landsat 5 Thematic Mapper), airborne thermal infrared imagery (FLIR), and various geospatial anthropogenic datasets collected by the Bureau of Reclamation (see fig. 3). The Landsat 5 Thematic Mapper dataset, captured in September 2000, is used to run a Normalized Difference Vegetation Index (NDVI) for evaluating landscape variability. The NDVI algorithm provides a continuous numerical statistic related to vegetation potential or greenness of each pixel in the image and is derived from the values of the red and near infra-red spectral bands of the satellite data. With this algorithm, each pixel within the watershed is attributed with a value that represents its potential to be green, healthy vegetation, as represented on a scale from 0 (low) to 200 (high). For this study, the NDVI metric is the primary landscape scale variable representing the state of the surrounding watershed at various spatial scales.

The FLIR thermal data were employed as the response variable representing in-stream temperature and its variability within the stream channel. The airborne thermal infrared (TIR) surveys were flown by Watershed Sciences, Inc. of Corvallis, Oregon, in August 2004 and were subsequently provided for this study as processed GIS point data. The continuous raw data images were sampled by querying pixel temperature values from the center of the stream channel and then calculating and exporting the median value of a 10-point sample of adjacent pixels. Note that each pixel covers approximately 812 m^2 in area and represents 28.5 m in distance from the stream channel. The temperatures of detectable surface inflows (i.e., surface springs, tributaries) also were sampled at their mouth. The resulting data layer followed the trend of the stream channel yielding point temperature summary statistics for the 10 pixels analyzed.

Additional data used in this research included geospatial information related to anthropogenic alterations to stream dynamics, including stream diversions, pumps, and water rights withdrawal sites. These data were collected by the Bureau of Reclamation (Pacific Northwest region) through the interpretation of high resolution aerial imagery and review of historical records. Point locations for these features were incorporated into the GIS and used to explore potential spatial relationships with in stream temperature patterns.

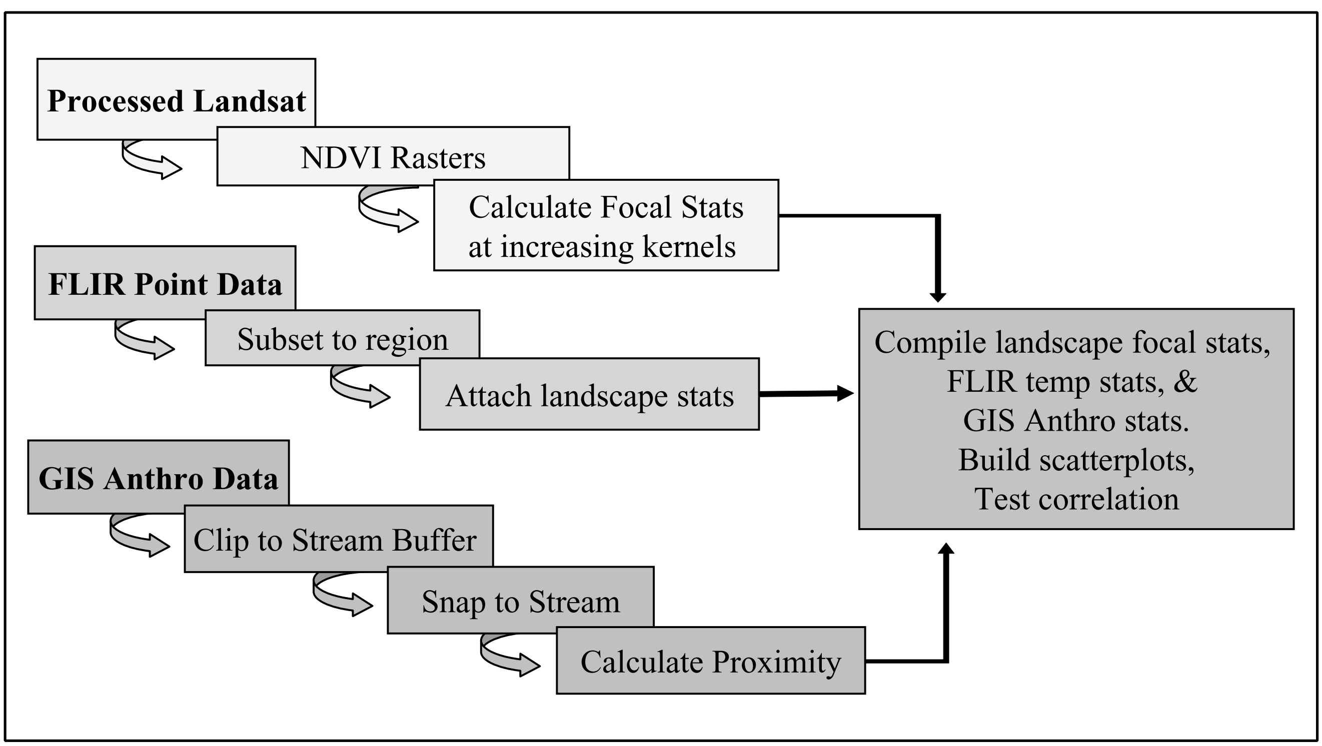

Figure 3. Workflow for processing the three main datasets used in this study. Each dataset was processed separately and then spatially joined for pair-wise regression.

Methods

The three above described datasets were processed and analyzed to explore the role that spatial scale plays in driving in stream habitat conditions, namely temperature. We first calculate summary statistics (maximum, minimum, standard deviation, median, average) on the NDVI data at varying spatial extents across the surrounding watershed. Using this approach, every stream pixel is attributed with watershed scale information through a GIS-based focal algorithm that calculates and associates surrounding landscape metrics to the stream pixel based on a user-defined kernel or analysis window (see fig. 4). A kernel is defined as a moving analysis window whose center pixel is attributed depending on the metric being analyzed (in this case NDVI values). The smallest kernel calculated metrics for a 3×3 pixel window to evaluate the landscape variables at a radius of 1 pixel around the stream channel on all sides. The stream channel itself was converted to null prior to running the model to exclude the water-based spectral signatures from the analysis. The kernel size was then increased incrementally up to a 19×19 pixel window.

The attributed stream pixels that were coincident with FLIR temperature data points were then extracted from the data layer and further attributed with the associated FLIR temperature data value. Pair-wise regression was then calculated between the landscape statistics and the temperature values to test how they co-vary as kernel size is increased.

The GIS point locations for water withdrawals and diversions was similarly processed to test against the in-stream temperature patterns. The point data were first subset to the area within 1,000 m from the centerline of the stream channel. Upstream distance and direction was calculated and attributed to each withdrawal point feature before it was spatially joined to the nearest downstream FLIR data point. Each FLIR data point that was linked to a withdrawal location was then extracted and used to run pair-wise regression between its standard deviation in temperature (from adjacent pixels) and the distance upstream of the water withdrawal/structure feature.

Results

The initial results from this study suggest that the condition of the landscape upland from the riparian corridor does indeed relate to measured in-stream water temperatures. The strength of the relationship between the in-stream temperature and the landscape variables (specifically the NDVI) appears to increase with kernel size (see fig. 5). That is, correlation appears to be strongest between landscapes evaluated at larger kernels (19×19), which capture more of the surrounding watershed composition and variability than kernels that simply evaluate the near-stream adjacent pixels of the riparian corridor. This preliminary conclusion implies that

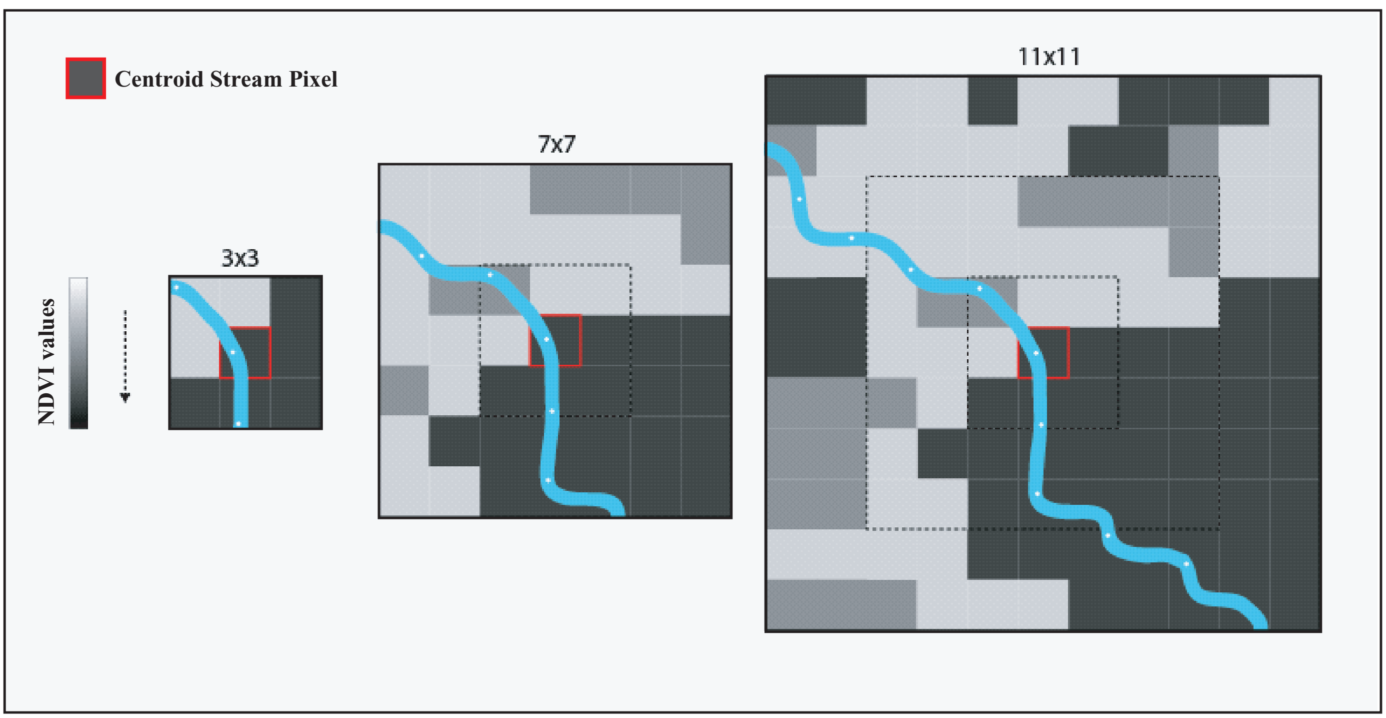

Figure 4. Schematic diagram illustrating a sample of the kernel analysis used in this study. The centroid stream pixel (outlined in red) is attributed with values that represent the statistics of NDVI for all the surrounding pixels in the kernel window. As the kernel size increases, more pixels are evaluated in the analysis and the resulting values represent a larger extent of the watershed.

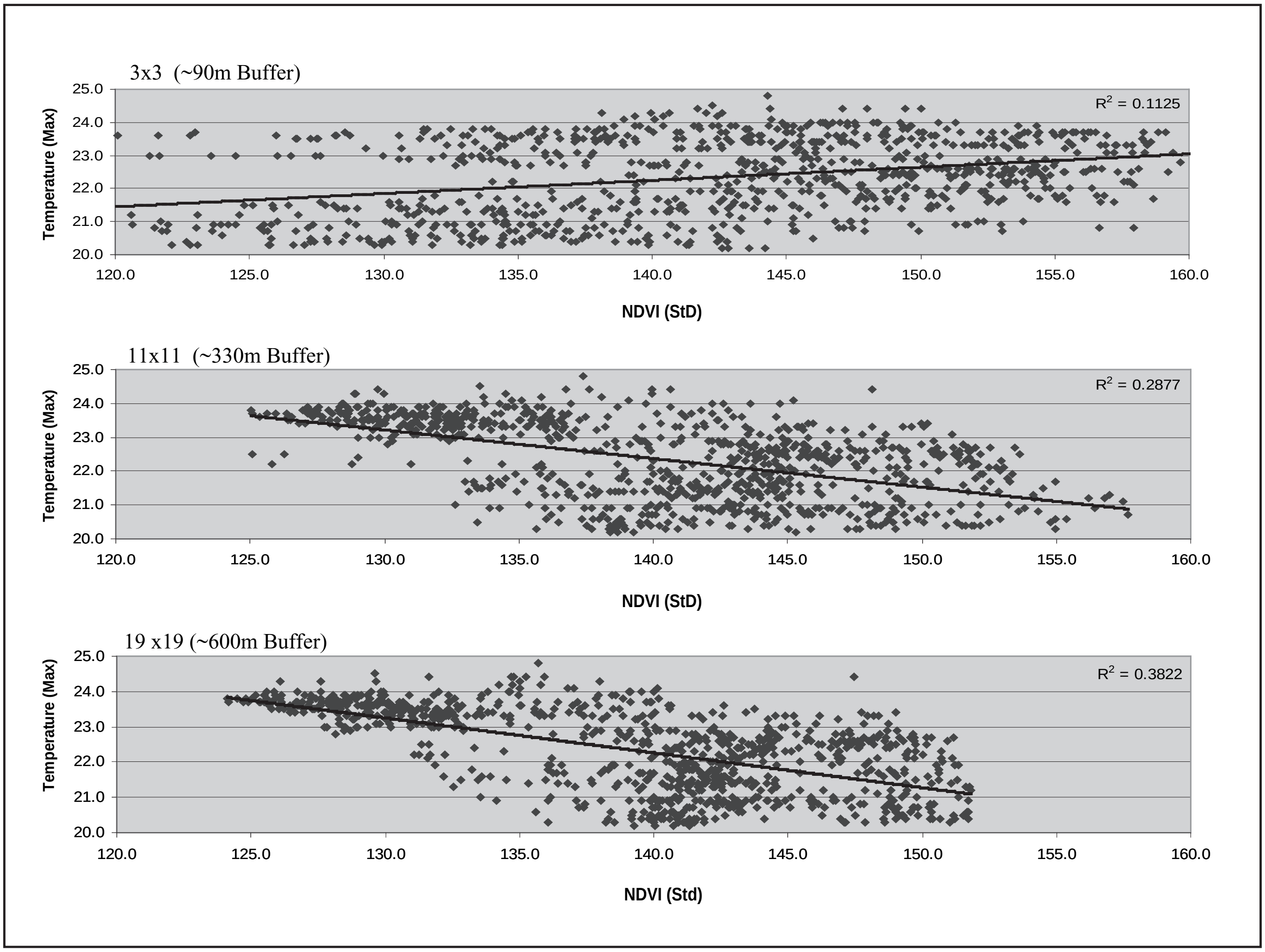

Figure 5. Results of pair-wise regression for kernel analysis showing the standard deviation in NDVI in NDVI pixels against the maximum temperature value for each pixel. Note how the coefficient of determination (r-squared) increases with increasing kernel size, indicating that the regression equation explains more of the variance in temperature as the kernel is increased.

the traditional riparian corridor setbacks designed to mitigate anthropogenic impacts on fluvial systems may be too narrow to adequately buffer streams from these external influences.

The proximity of water withdrawals, pumps, and diversion structures to the stream channel also appears to show correlation to in-stream water temperature (see fig. 6). Subsampling the original data to within 1 km of the stream channel, found there are 65 structures near or adjacent to the stream at varying distances. When spatially joined to the nearest downstream temperature data point, the scatterplot of the distance versus recorded temperatures indicate that the closer the structures are to the channel, the higher the standard deviation of the recorded in-stream water temperatures. These initial results suggest that notable downstream fluctuations in water temperatures may be linked to the presence of water withdrawal and other anthropogenic structures present near the stream channel.

Conclusions

This study has shown that there is value in utilizing landscape scale satellite imagery for assessing the role of watershed conditions with respect to in stream habitat conditions. The availability of reliable GIS and remote sensing data regarding the presence and location of near stream structures, and other anthropogenic alterations to the landscape can even further the potential for modeling stream habitat and understanding the role that humans play in regulating the availability of suitable fish habitat. In summary, this study has shown that:

- Streams respond to the landscape beyond the traditionally recognized narrow riparian buffer;
- Vegetation metrics derived at the landscape level can be correlated with habitat conditions measured in the stream, specifically temperature;

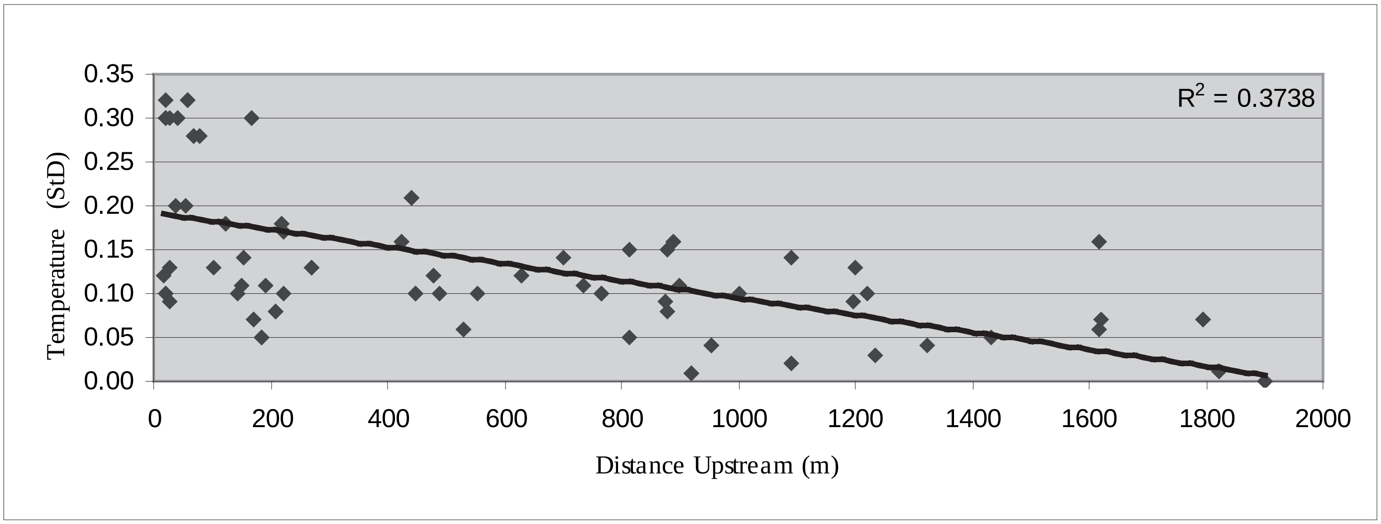

Figure 6. Preliminary pair-wise correlation results for geospatial analysis of water diversion, withdrawal and pump data as they relate to in-stream temperature. Nearly 38% of the variance in downstream water temperatures can be explained by the presence and proximity of a water diversion, pump or withdrawal structure.

- Watershed land use and disturbance plays an important role in driving local stream habitat conditions;
- Water rights and stream diversions impact local temperature regimes, however to what extent is unclear;
- Accurate mapping of the locations of these diversions will assist in more accurate modeling of local temperature fluctuations.

The initial findings of this research are preliminary and will continue to be verified and expanded upon to include other remote sensing data (e.g., Advanced Spaceborne Thermal Emission and Reflection Radiometer), additional stream channel alteration information, ground truth validation, correlation outlier analysis, and multivariate regression. However, these results in their present form do lend valuable consideration to how remote sensing can be applied to inform watershed management and stream habitat restoration strategies.

Acknowledgments

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